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INFLUENCE OF DYNAMIC FRACTURE TOUGHNESS ON DYNAMIC CRACK PROPAG--ETC(U)
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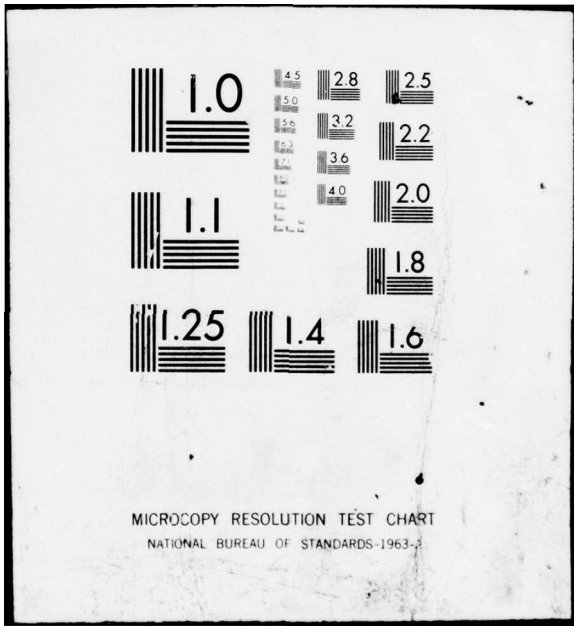
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12 25 p.

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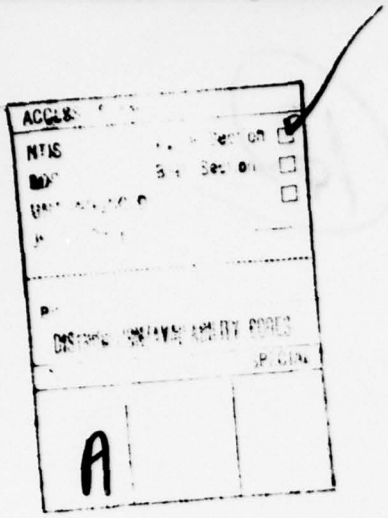

INFLUENCE OF DYNAMIC FRACTURE TOUGHNESS ON DYNAMIC CRACK PROPAGATION

by

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ABSTRACT

A dynamic finite element code was used in its "propagation mode" to assess the differences in dynamic crack propagation in a wedge-loaded (WL) single-edged notch (SEN) specimen, a tapered double cantilever beam (TDCB) specimen and a rectangular double cantilever beam (RDCB) specimen. The dynamic fracture toughness, K_{ID}, versus the crack velocity, $\dot{a}$, relations determined experimentally for WL-SEN, WL-TDCB and WL-RDCB specimens machined from Araldite B were used as dynamic fracture criteria and the resultant K_{ID} variations with crack propagations in the three specimens were compared with the corresponding experimental results. While the specific K_{ID} versus $\dot{a}$ relations established for each specimen obviously yielded calculated K_{ID} which were in best agreement with the experimental K_{ID} for the respective specimen, the K_{ID} versus $\dot{a}$ relation for the large WL-SEN specimen provided the best overall fit between the calculated and measured K_{ID} variations with crack propagation in all three specimens.

INTRODUCTION

During the past several years, dynamic photoelasticity [1-3] and dynamic caustic [4,5] have been used in an attempt to identify a fundamental law which governs dynamic crack propagation in solids. These optical techniques provide the near-field, dynamic state of stress surrounding a running crack and thus offer means of extracting the dynamic stress intensity factor associated with this stress field. Although most of these investigations have been confined to the studies of dynamic responses in polymers, birefringent coating technique [6] and reflection caustic [5] are being used to extend these optical techniques for studying dynamic fracture of metals. All investigations using these optical techniques, however, have been confined to the dynamic analyses of fracture specimens of specific geometries. It is interesting to note that the University of Maryland (UM) [1,2] group chose relatively large Homalite-100 fracture specimens in comparison to the smaller Homalite-100 specimens used at the University of Washington (UW) [3] and the group at the Institut für Festkörper-mechanik (IFKM) [4, 5] used medium and small size Araldite B specimens. The resultant dynamic stress fracture toughness, K_{ID}, versus crack velocity relation, $\dot{a}$, obtained by the UM group showed that the K_{ID} versus $\dot{a}$ relation for Homalite-100 to be essentially independent of specimen configurations. The UW and IFKM results in Homalite-100 and Araldite B, respectively, on the other hand, showed K_{ID} versus $\dot{a}$ relation to be somewhat dependent on specimen geometry.

These differences, which admittedly are not excessive, in K_{ID} versus $\dot{a}$ relations pose a fundamental question as to whether dynamic crack propagation is solely governed by the current state of crack tip stresses, which are characterized by the dynamic fracture toughness of K_{ID}, or whether it should

carry the influence of past propagation history such as the rate of change of dynamic fracture toughness, $\dot{K}_{ID}$. The latter obviously would not allow K_{ID} versus $\dot{a}$ to be a unique material property. In spite of this controversy, past numerical analysis [7] has indicated that perhaps variations in the K_{ID} versus $\dot{a}$ relation do not substantially affect the total dynamic motion leading the authors to question the sensitivity of the calculated dynamic crack propagation to the specific K_{ID} versus $\dot{a}$ relation used.

The authors thus undertook a sensitivity study using the IFKM test results which included smaller fracture specimens machined from previously fractured larger specimens and which reduced the material variability in establishing K_{ID} versus $\dot{a}$ relations for the various fracture specimens. In the following some of the salient features of this study are reported.

DYNAMIC FRACTURE ANALYSIS

The recent revisions made in the authors' previously updated dynamic finite element code [8] are discussed in detail in Reference [9]. Briefly, the most recent improvements include a better controlled numerical algorithm prescribing nodal force at the crack tip node during crack extension in the explicit dynamic finite element code of HONDO [10]. Fracture energy was computed from the dissipated energy using the force and displacement at the nodal point being released. The dynamic stress intensity factor was then computed from the fracture energy using Freund's relation [11]. The improved dynamic fracture mechanics code was first used in its "propagation" and then in its "generation" modes, as designated by Kanninen [12], of crack propagation in order to verify the internal consistency of the total fracture mechanics package.

The improved code was then used both in its propagation and generation modes to analyze two fracturing wedge-loaded, rectangular double cantilever beam (WL-RDCB) specimen tested by Kalthoff et al. [13]. Negligible differences between the two numerical K_{ID} throughout the fracture process obtained through the propagation and generation modes proved the sought internal consistency of the code. Good agreement between the numerically and experimentally determined K_{ID} further showed the validity of the dynamic fracture model used. It was also shown that when the generation mode is used in conjunction with the measured crack position versus time data, experimental errors in the latter could grossly distort the computed K_{ID} values. The inevitable limitation in crack position measurements was overcome by using the smoothed crack position versus time as well as an associated smoothed crack velocity relation as input data in the generation calculations.

The above studies also showed that the propagation calculation resulted in less oscillations in the calculated K_{ID} but the calculated and measured crack lengths at crack arrest were not always in complete agreement. This sensitivity of the arrest crack length to input K_{ID} versus $\dot{a}$ relation in the propagation calculation made it ideal for the sensitivity study reported in this paper.

FRACTURE SPECIMENS AND MATERIAL DATA

The three specimens which were analyzed by the dynamic finite element code are the wedge-loaded (WL) single-edge notched (SEN) specimen, rectangular double cantilever beam (RDCB) specimen and tapered double cantilever beam (TDCB) specimen which were machined from a 10 mm thick Araldite B and analyzed with dynamic caustics by Kalthoff et al. [4,5]. The specimen geometries are given in Figure 1 and a typical finite element breakdown of the WL-SEN specimen is given in Figure 2. The finite element breakdown used for the WL-RDCB and

WL-TDCB specimens are similar to those used in Reference [9] with an obvious reduction in scale.

Extensive experimental investigation by Hahn et al. [7] has shown that the wedge-loaded pins could leave the wedge and travel outwards in the steel specimens. When such pin motion is accounted for in K_{ID} computation, an attendant increase in the K_{ID} during crack propagation was observed [14]. The additional input energy due to any possible separation of the steel loading pins from the steel wedge should be considerably smaller due to the smaller mass density and the two orders of magnitude larger compliance of the Araldite B specimens in comparison to the steel specimen studied in Reference [14]. Thus the possible loading pin motion was ignored and constant displacements were prescribed at the pin holes in the dynamic finite element analysis.

Material constants of Araldite B used for this analysis are modulus of elasticity E = 3.38 GPa, Poisson ratio of ν = 0.33 and mass density, ρ = 1047 kg/m^3. Dynamic fracture toughness K_{ID}, versus crack velocity, $\dot{a}$, relations shown in Figure 3, are based on the experimental data from Ref. [15].

Since the dynamic crack initiation stress intensity factors, K_{IQ}, were not reported in Reference [15] for any of the three specimens, K_{IQ}s were either back-calculated by static analysis using the estimated mean values of oscillating K_{ID} values for the WL-RDCB and WL-TDCB specimens or estimated for the WL-SEN specimen. Given the K_{IQ} value and one of the three K_{ID} versus $\dot{a}$ relations, the crack was propagated dynamically in the WL-SEN, WL-TDCB and WL-RDCB specimens using the improved fracture dynamic code.

RESULTS

WL-SEN Specimen

The first numerical analysis involved a propagation analysis of the WL-SEN specimen of Figure 1 using three K_{ID} versus $\dot{a}$ relations of Figure 3 and a K_{IQ} = 1.08 MPa $\sqrt{m}$. The resultant K_{ID} crack tip motion of this propagation calculation are shown in Figures 4 and 5, respectively. Significant differences are noted especially in the second two thirds of crack propagation prior to crack arrest, where the two curves obtained by using the K_{ID} versus $\dot{a}$ relations for the WL-TDCB and WL-RDCB specimens grossly underestimate by more than a factor of two the total jump distance at crack arrest.

Figure 5 shows that the computed crack propagation time using the K_{ID} versus $\dot{a}$ relation is about one half and two thirds, respectively, of the actual propagation time. The underestimation in computed crack arrest length and time using the K_{ID} versus $\dot{a}$ relations of the WL-TDCB and WL-RDCB is due to the fact that the propagation calculation is terminated when the computed dynamic stress intensity factor falls below the minimum K_{ID} values in Figure 3 thus indicating the extreme sensitivity of these values to the seemingly small shifts in the minimum K_{ID}.

WL-TDCB Specimen

Figure 6 shows the K_{ID} as a function of $\dot{a}$ of a WL-TDCB specimen again using the three K_{ID} versus $\dot{a}$ relations of Figure 3 and K_{IQ} = 2.08 MPa $\sqrt{m}$. The pronounced second maximum in K_{ID} seen in the WL-SEN specimen as well as in the previously analyzed large WL-RDCB specimen [9], is considerably smaller in the current WL-TDCB specimen. The computed jump distances at crack arrest obtained by the use of the three K_{ID} versus $\dot{a}$ relations are in reasonable agreement with experimental results. Although not obvious from Figure 6,

the computed K_{ID} increased again after the initial crack arrest to a value approaching the measured K_{ID} at crack arrest if a slow crack propagation was prescribed just after the arrest.

Figure 7 shows the K_{ID} versus time relation for a WL-TDCB specimen using the three K_{ID} versus $\dot{a}$ relations. Although the three calculated K_{ID} are in excellent agreement with each other, the calculated crack arrest times are considerably smaller than that found experimentally.

Figure 8 shows the computed K_{ID} for a WL-RDCB specimen using the three K_{ID} versus $\dot{a}$ relations and a K_{IQ} = 2.0 MPa $\sqrt{m}$. Note that the crack length at crack arrest obtained by using the K_{ID} versus $\dot{a}$ relations for large WL-SEN and small WL-TDCB specimens are approximately 5% larger and smaller, respectively, than the measured crack length at crack arrest. Interestingly enough, all the three calculations underpredict the time to crack arrest as shown by Figure 9.

CONCLUSIONS

Propagation studies of three Araldite B dynamic fracture specimens, i.e. WL-SEN, WL-TDCB and WL-RDCB, using the individually generated K_{ID} versus $\dot{a}$ relations showed that best agreement between calculated and measured K_{ID} values can be obtained, as expected when the respective K_{ID} versus $\dot{a}$ relation is used in analyzing each specimen.

Calculated crack arrest length and crack arrest time for a WL-SEN specimen with small variations in K_{ID} are sensitive to the slight shift in the minimum dynamic stress intensity factor, K_{Im}, in the K_{ID} versus $\dot{a}$ relation.

In this study conservative estimates of the crack arrest lengths in the small specimens, i.e. WL-TDCB and WL-RDCB can be obtained by using the K_{ID} versus $\dot{a}$ relation with the smallest K_{Im}, i.e. the relation generated by the larger WL-SEN specimen.

DISCUSSIONS

Although only three dynamic fracture specimens were studied in this paper, this comparative study indicates that the specimen dependent K_{ID} versus $\dot{a}$ relation advocated by some [3,4,5] is valid. If such is the case, the results also imply that dynamic propagation of a crack is not controlled solely by the instantaneous dynamic state surrounding a running crack and that further fundamental investigation on the law(s) governing dynamic crack propagation is necessary. Crack propagation in the presence of severe dynamic loadings, such as impact loading of a small fracture specimen [6,7] could accentuate such dynamic conditions and thus warrants further investigation.

In the interim, however, conservative estimates of the dynamic crack propagation response and the crack length at crack arrest can be made by using the minimum K_{ID} at the knee and a maximum K_{ID} at the shelf of a K_{ID} versus $\dot{a}$ relation which in this study happens to be that extablished for large WL-SEN.

ACKNOWLEDGEMENTS

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REFERENCES

1. Kobayashi, T. and Dally, J.W., "The Relation Between Crack Velocity and Stress Intensity Factor in Birefringent Polymers," Fast Fracture and Crack Arrest, ASTM STP 627, 1977, pp. 257-273.

2. Irwin, G.R., Dally, J.W., Kobayashi, T., Fourney, W.L., and Etheridge, J.M., "Photoelastic Studies of Crack Propagation and Crack Arrest," a University of Maryland report prepared under U.S. Nuclear Regulatory Commission Contract AT(49-24)-0172, Sept. 1977.

3. Kobayashi, A.S. and Mall, S., "Dynamic Fracture Toughness of Homalite-100," Experimental Mechanics, Vol. 18, No. 1, Jan. 1978, pp. 11-18.

4. Kalthoff, J., "Effect of Specimen Geometry on Crack Arrest Toughness," a paper presented at the Joint ASME/CSME Pressure Vessel and Piping Conf., Montreal, Canada, June 25-30, 1979.

5. Kalthoff, J., Beinert, J., and Winkler, S., "Experimental Analysis of Dynamic Effects in Different Crack Arrest Specimens," a paper presented at the ASTM E-24 Symposium on Crack Arrest Methodology and Applications, Philadelphia, Nov. 6-7, 1978.

6. Kobayashi, T. and Dally, J.W., "Dynamic Photelastic Characterization of Instantaneous Stress Intensity Factor for 4340 Alloy Steel," ibid loc. cit.

7. Hahn, G.T., Gehlen, P.C., Hoagland, R.G., Marshall, C.W., Kanninen, M.F., Popelar, C., and Rosenfield, A.R., "Critical Experiments, Measurements and Analyses to Establish a Crack Arrest Methodology for Nuclear Pressure Vessel Steels," a Battelle Columbus Laboratories report prepared under U.S. Nuclear Regulatory Commission Contract No. W-7405-Ing-92, Oct. 1976, BMI-NUREG-1959.

8. Kobayashi, A.S., Mall, S., Urabe, Y., and Emery, A.F., "A Numerical Dynamic Fracture Analysis of Three Wedge-Loaded DCB Specimens," Numerical Methods in Fracture Mechanics, edited by A.R. Luxmoore and D.R.J. Owens, University College of Swansea, Jan. 9-13, 1978, pp. 673-684.

9. Hodulak, L., Kobayashi, A.S., and Emery, A.F., "A Critical Examination of a Numerical Fracture Dynamic Code," a paper submitted for presentation at the 12th ASTM Annual Symposium on Fracture Mechanics, Washington University, May 20-23, 1979.

10. Key, S.W., "HONDO, A Finite Element Computer Program for the Large Deformation Responses of Axisymmetric Solids," Sandia Laboratories.

11. Freund, L.B., "Crack Propagation in an Elastic Solid Subjected to General Loading-II Non-Uniform Rate of Extension," J. of Mechanics and Physics of Solids, Vol. 20, 1972, pp. 141-152.

12. Kanninen, M.F., "A Critical Appraisal of Solution Techniques in Dynamic Fracture Mechanics," Numerical Methods in Fracture Mechanics, edited by A.R. Luxmoore and D.R.J. Owens, University College of Swansea, Jan. 1978, pp. 612-633.

13. Kalthoff, J., Beinert, J., and Winkler, S., "Measurements of Dynamic Stress Intensity Factors for Running and Arresting Cracks in Double-Cantilever-Beam Specimens," Fast Fracture and Crack Arrest, ASTM STP 627, July 1977, pp. 161-176.

14. Kobayashi, A.S., Urabe, Y. Emery, A.F., and Love, W.J., "Dynamic Finite Element Analyses of Two Compact Specimens," J. of Engineering Materials and Technology, Trans. of ASME, Vol. 100, No. 4, Oct. 1978, pp. 402-410.

15. Kalthoff, J.F., Beinert, J., and Winkler, S., "Influence of Dynamic Effect on Crack Arrest," an Institut fur Festkorpermechanik report prepared under Electric Power Research Institute Contract RP 1022-1 Aug. 1978, IKFM 40412.

16. Mall, S., Kobayashi, A.S.., and Urabe, Y., "Dynamic Photoelastic and Dynamic Finite-element Analyses of Dynamic-tear-test Specimens," Experimental Mechanics, Vol. 18, No. 12, Dec. 1978, pp. 449-456.

17. Mall, S., Kobayashi, A.S., and Urabe, Y., "Dynamic Photoelastic and Dynamic Finite Element Analyses of Polycarbonate Dynamic-tear-test Specimens," to be published in ASTM STP, 1979.

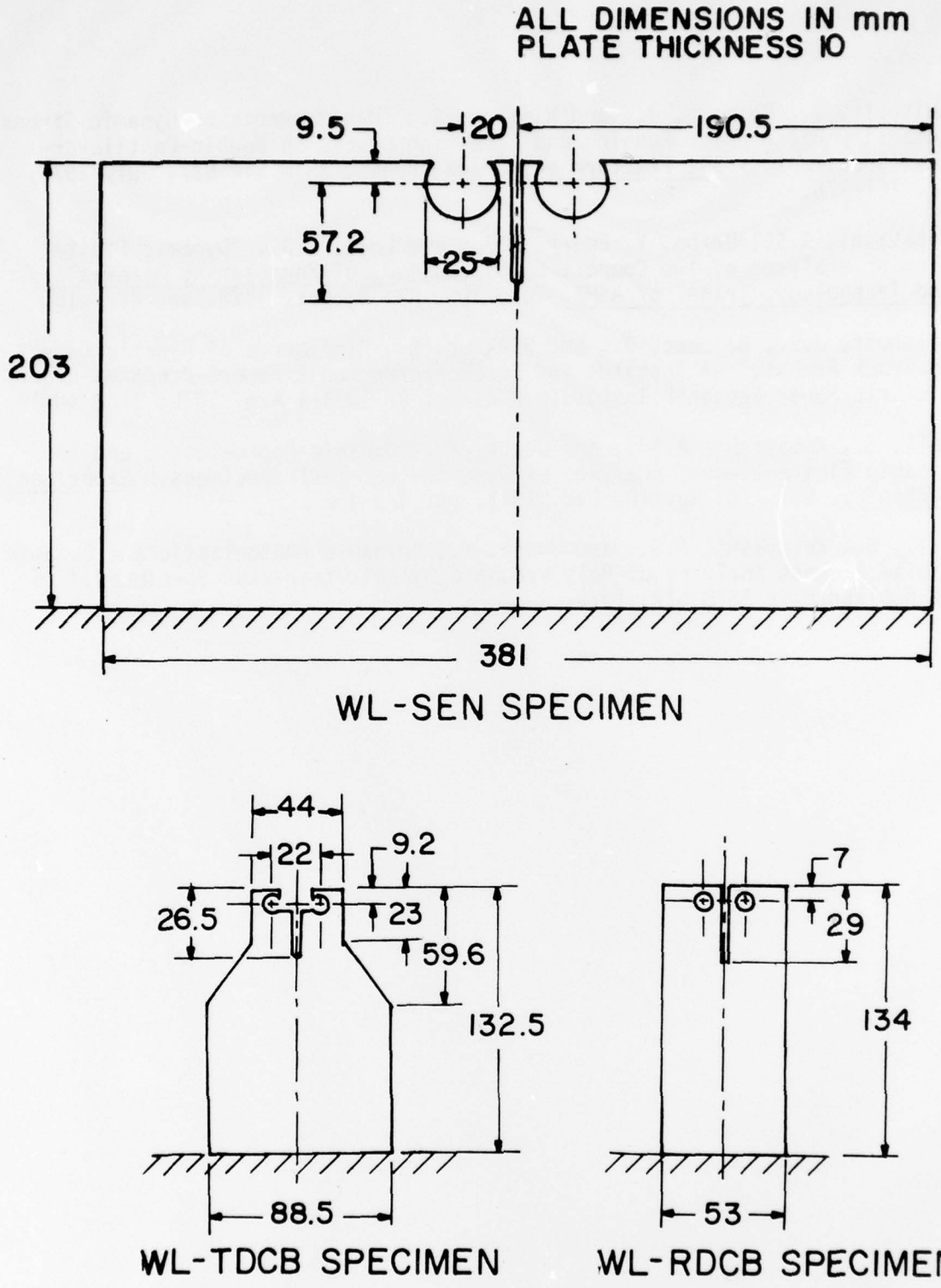

FIGURE 1. THREE DYNAMIC FRACTURE SPECIMENS:
WEDGE LOADED SINGLE-EDGED NOTCH SPECIMEN (WL-SEN).
WEDGE LOADED TAPERED DOUBLE CANTILEVER BEAM SPECIMEN (WL-TDCB).
WEDGE LOADED RECTANGULAR DOUBLE CANTILEVER BEAM SPECIMEN (WL-RDCB).

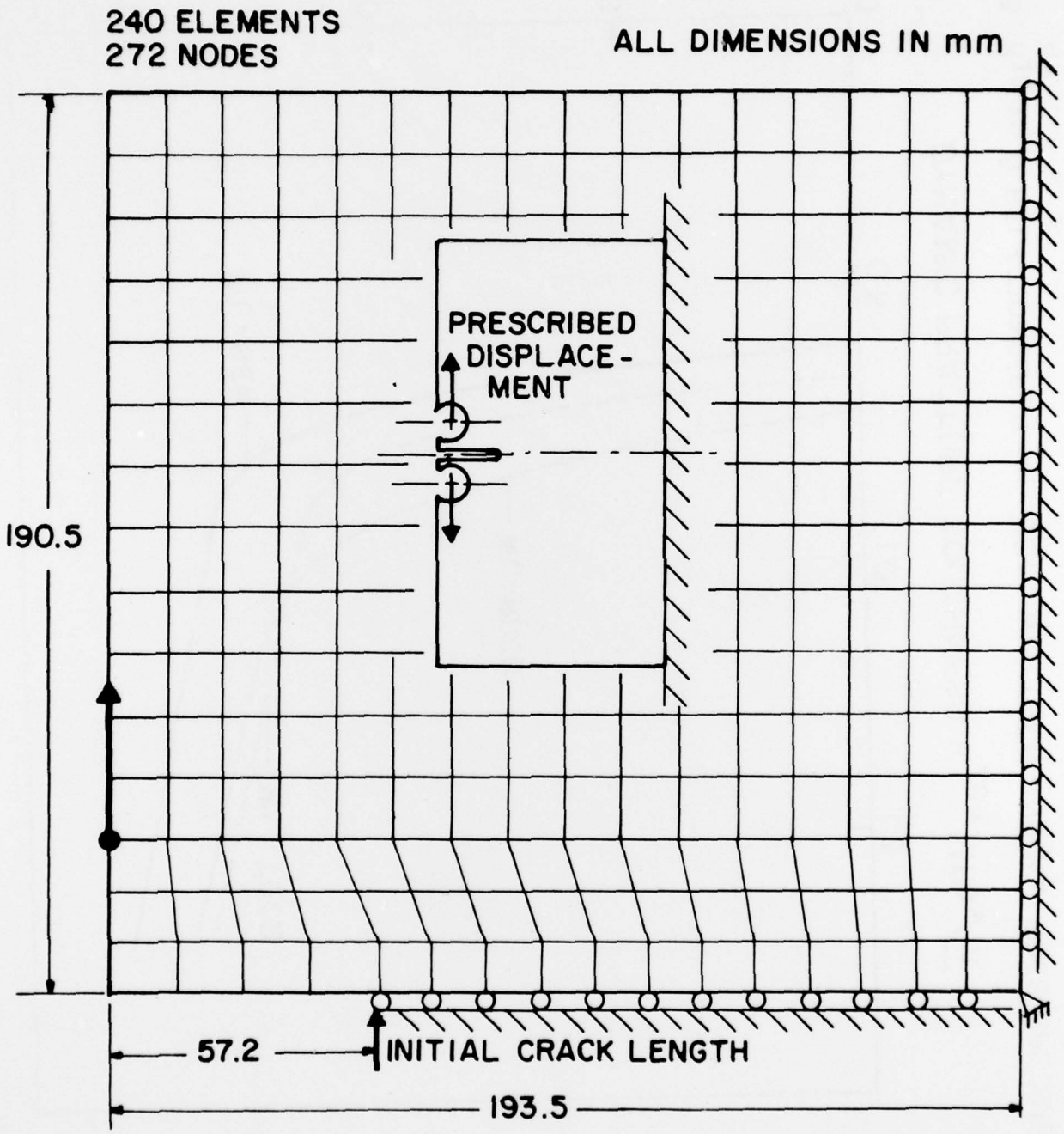

FIGURE 2. FINITE ELEMENT BREAKDOWN OF WL-SEN SPECIMEN.

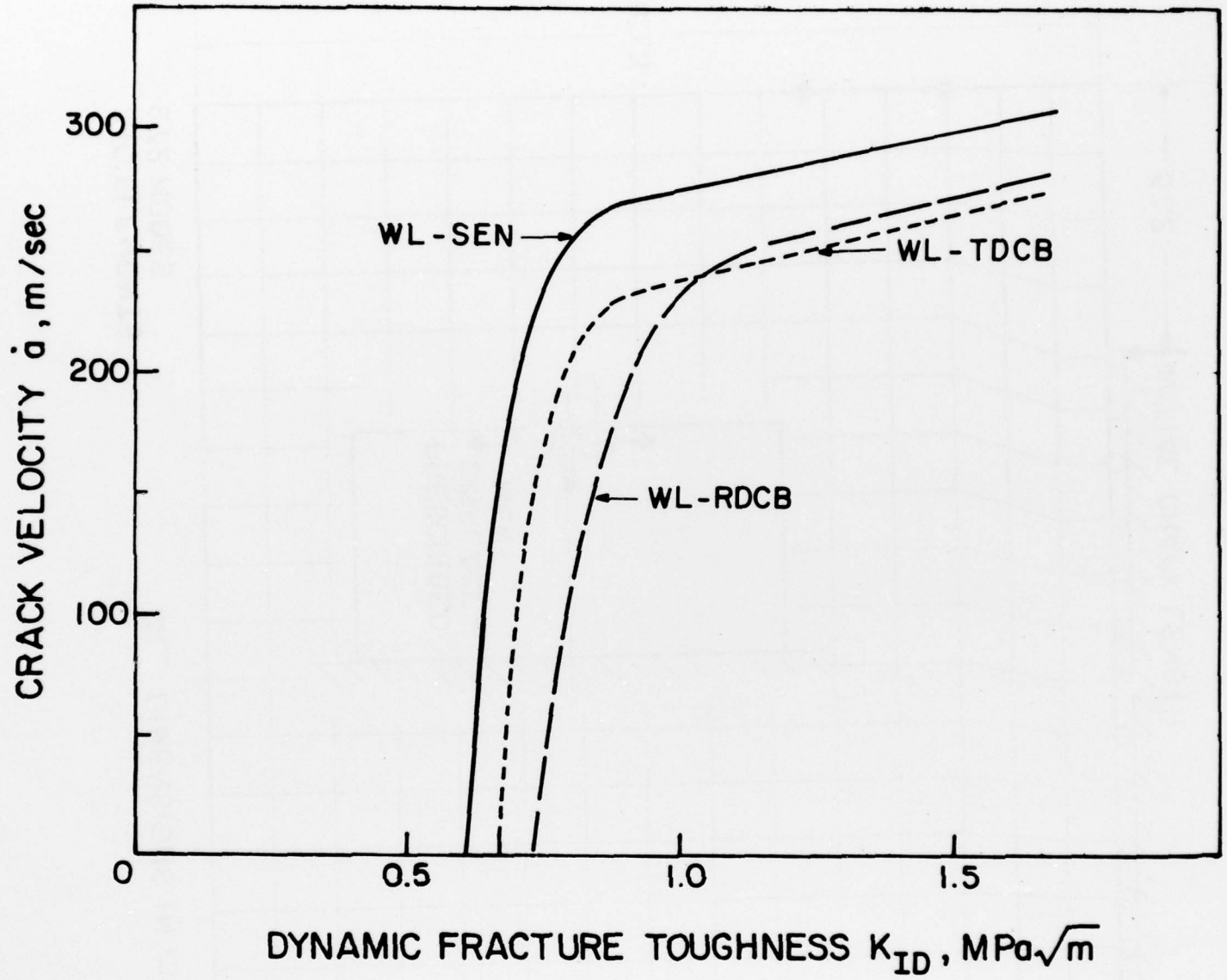

FIGURE 3. K_{ID} vs ȧ RELATIONS FOR WL-SEN, WL-TDCB AND WL-RDCB SPECIMENS ARALDITE B.

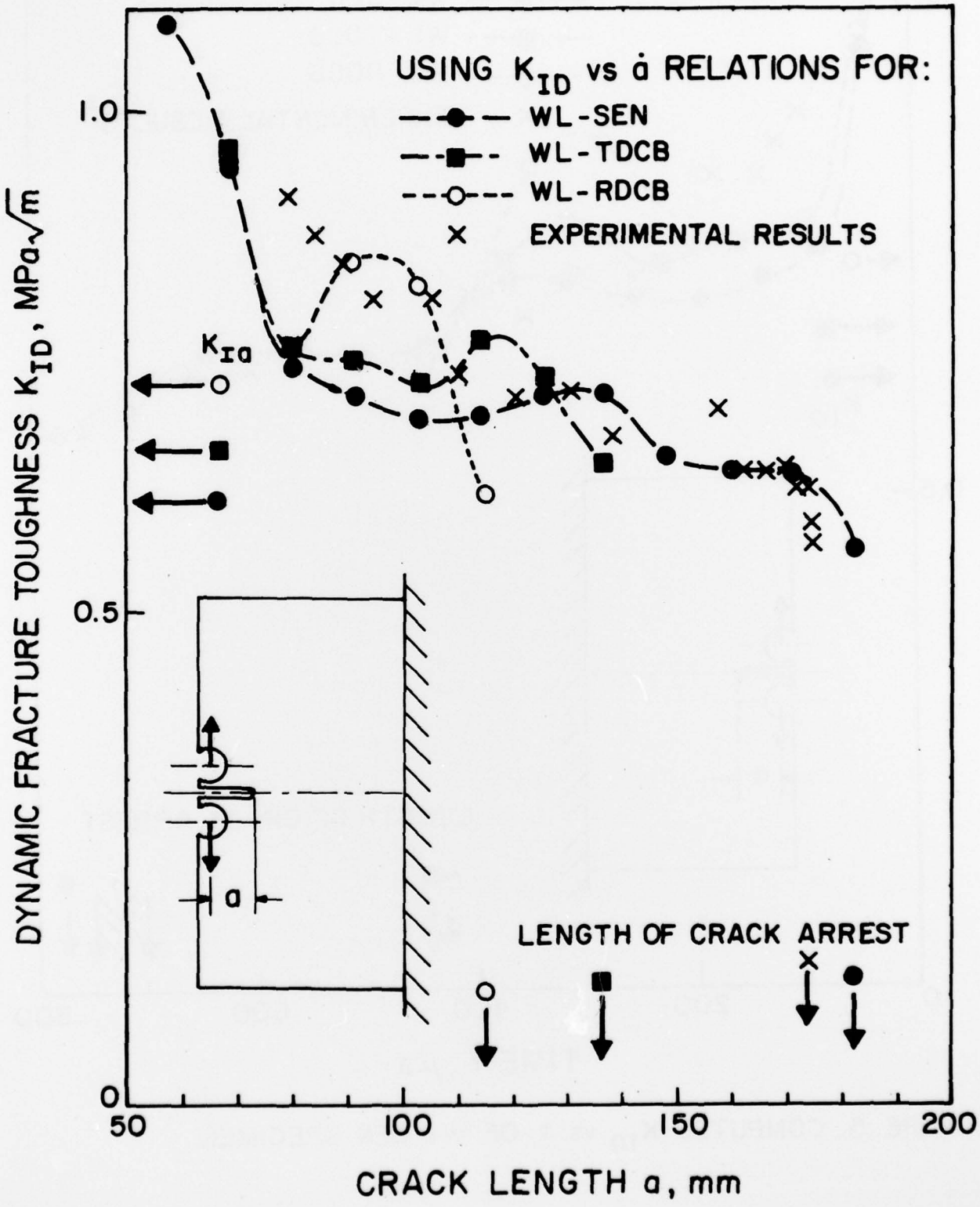

FIGURE 4. COMPUTED K_{ID} vs a OF WL-SEN SPECIMEN.

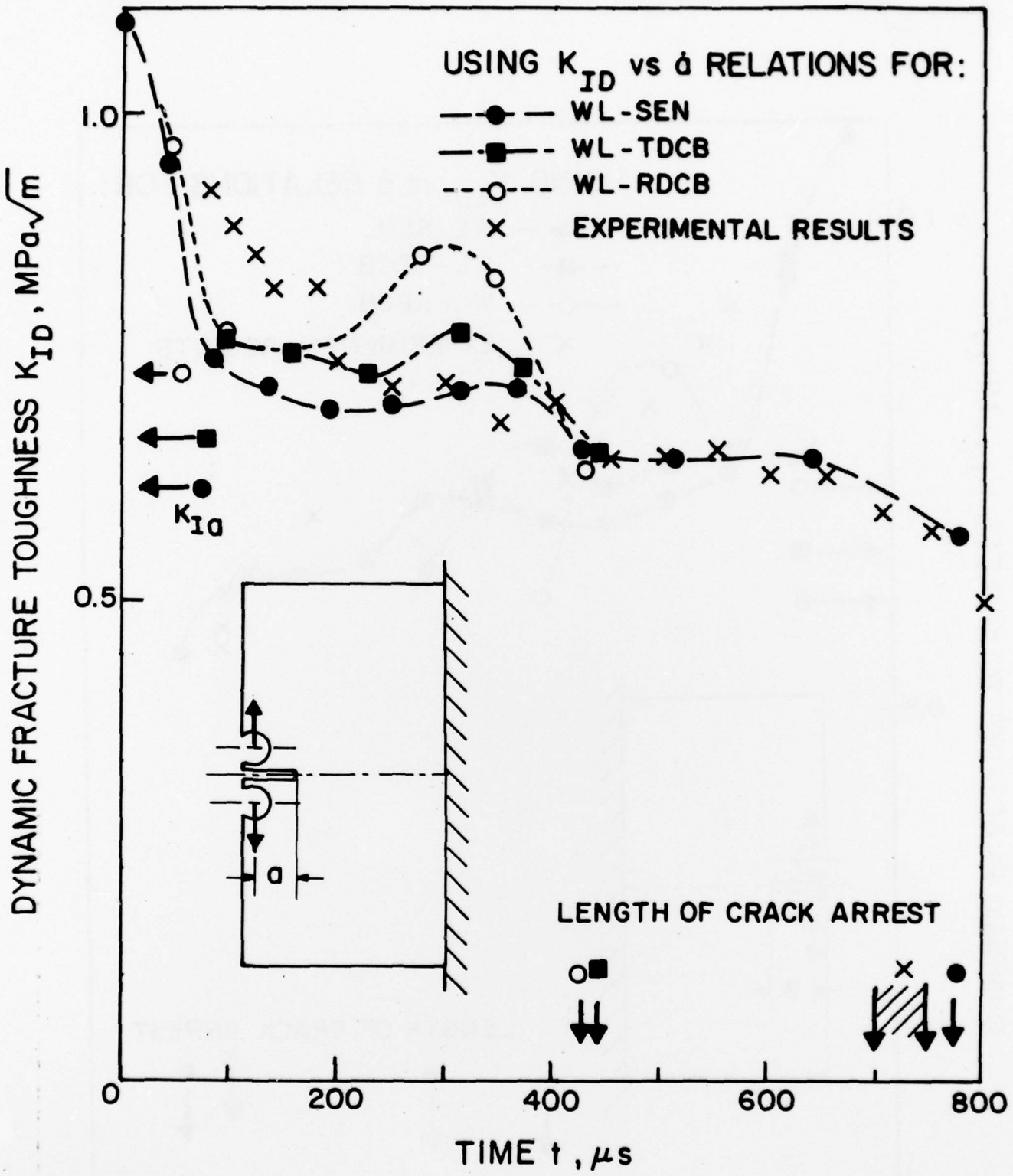

FIGURE 5. COMPUTED K_{ID} vs t OF WL-SEN SPECIMEN.

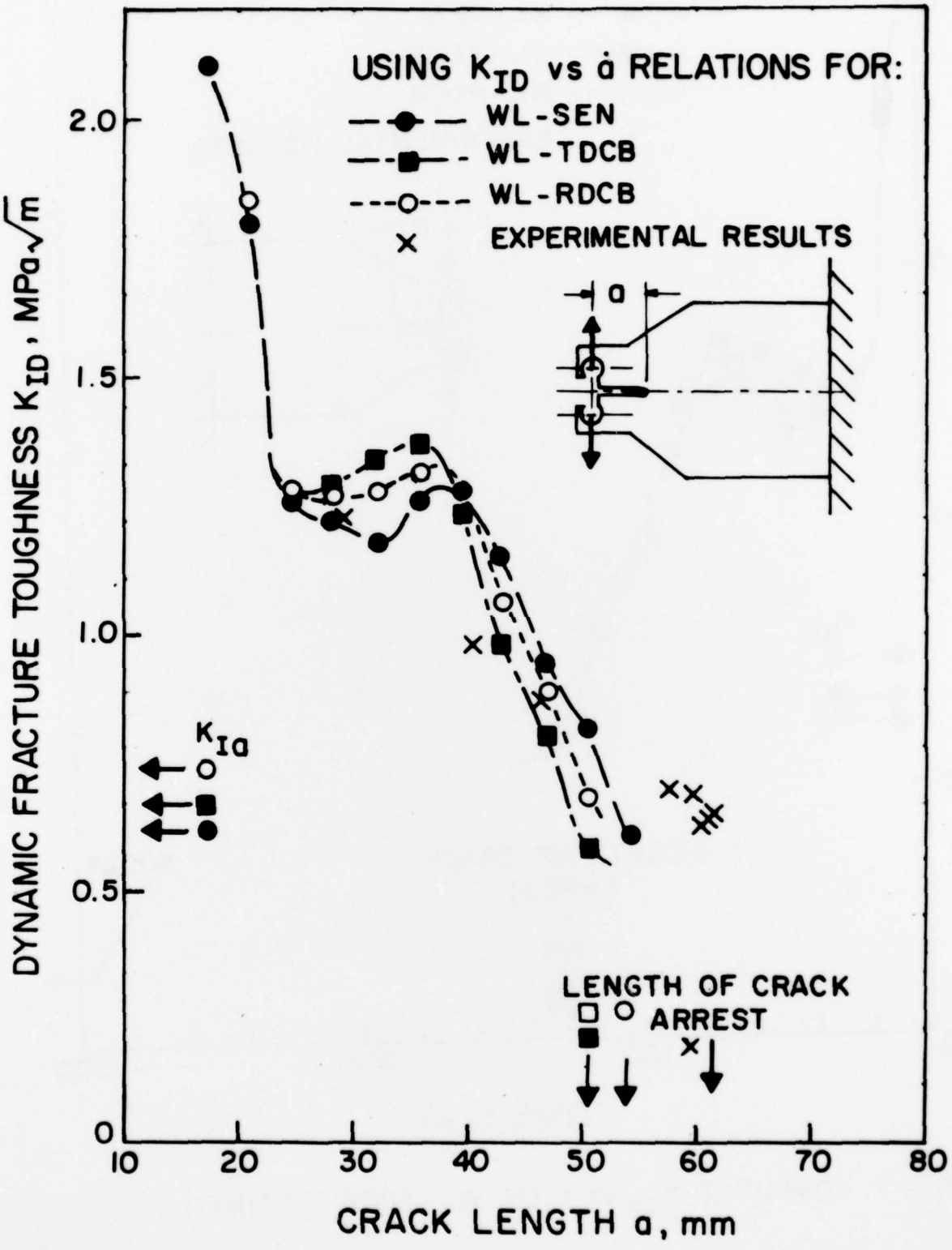

FIGURE 6. COMPUTED K_{ID} vs a OF WL-TDCB SPECIMEN.

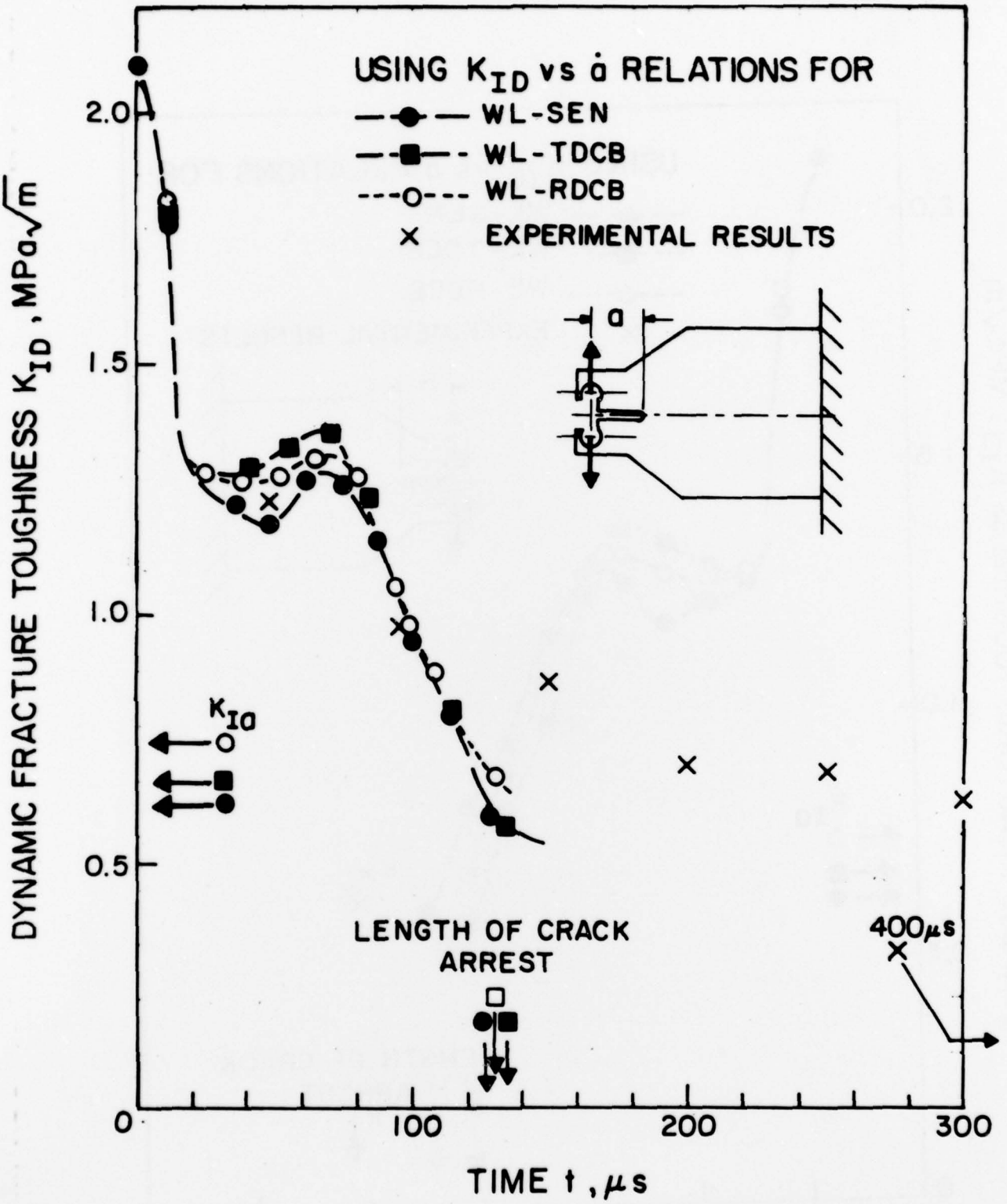

FIGURE 7. COMPUTED K_{ID} vs t OF WL-TDCB SPECIMEN.

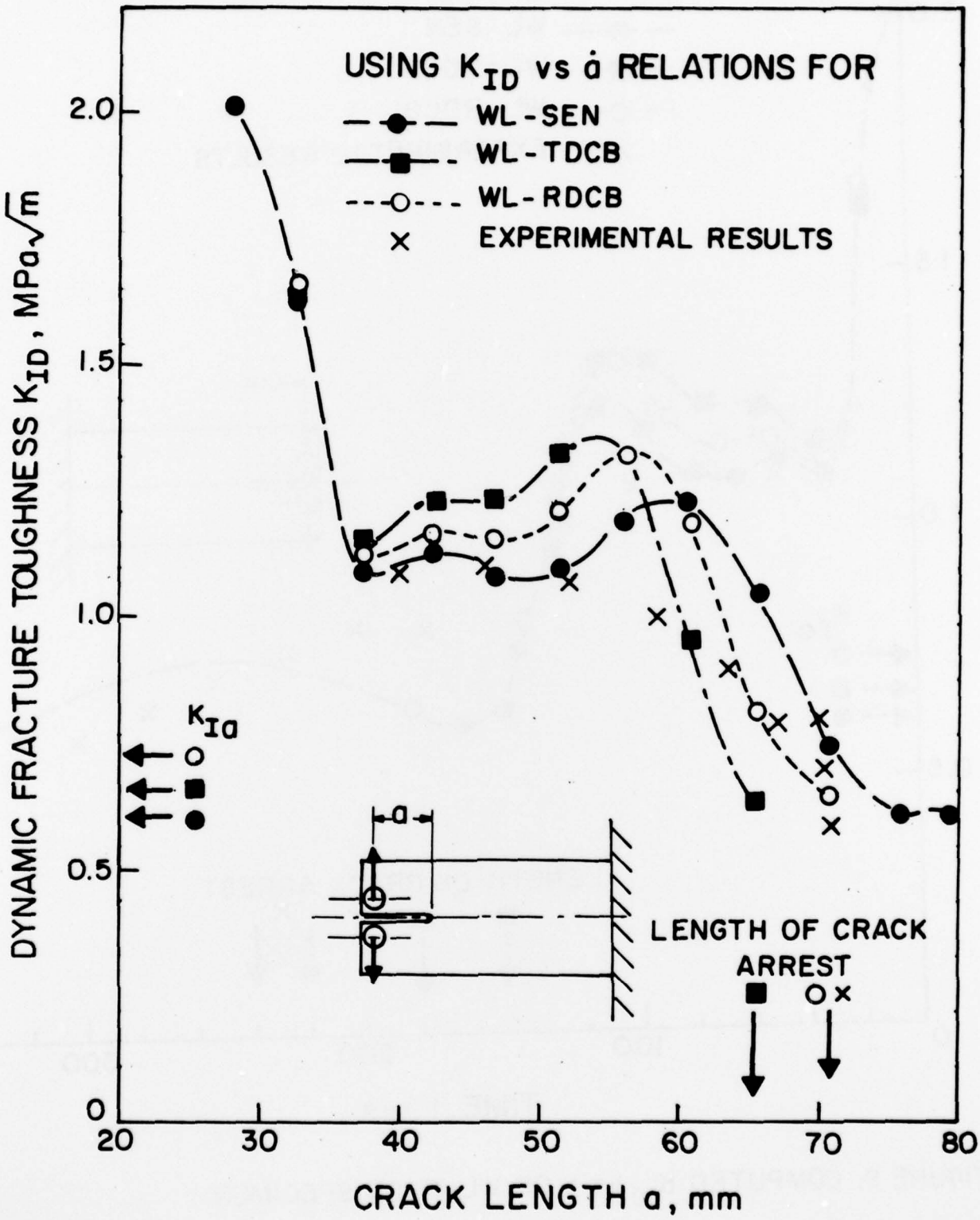

FIGURE 8. COMPUTED K_{ID} vs a OF WL-RDCB SPECIMEN.

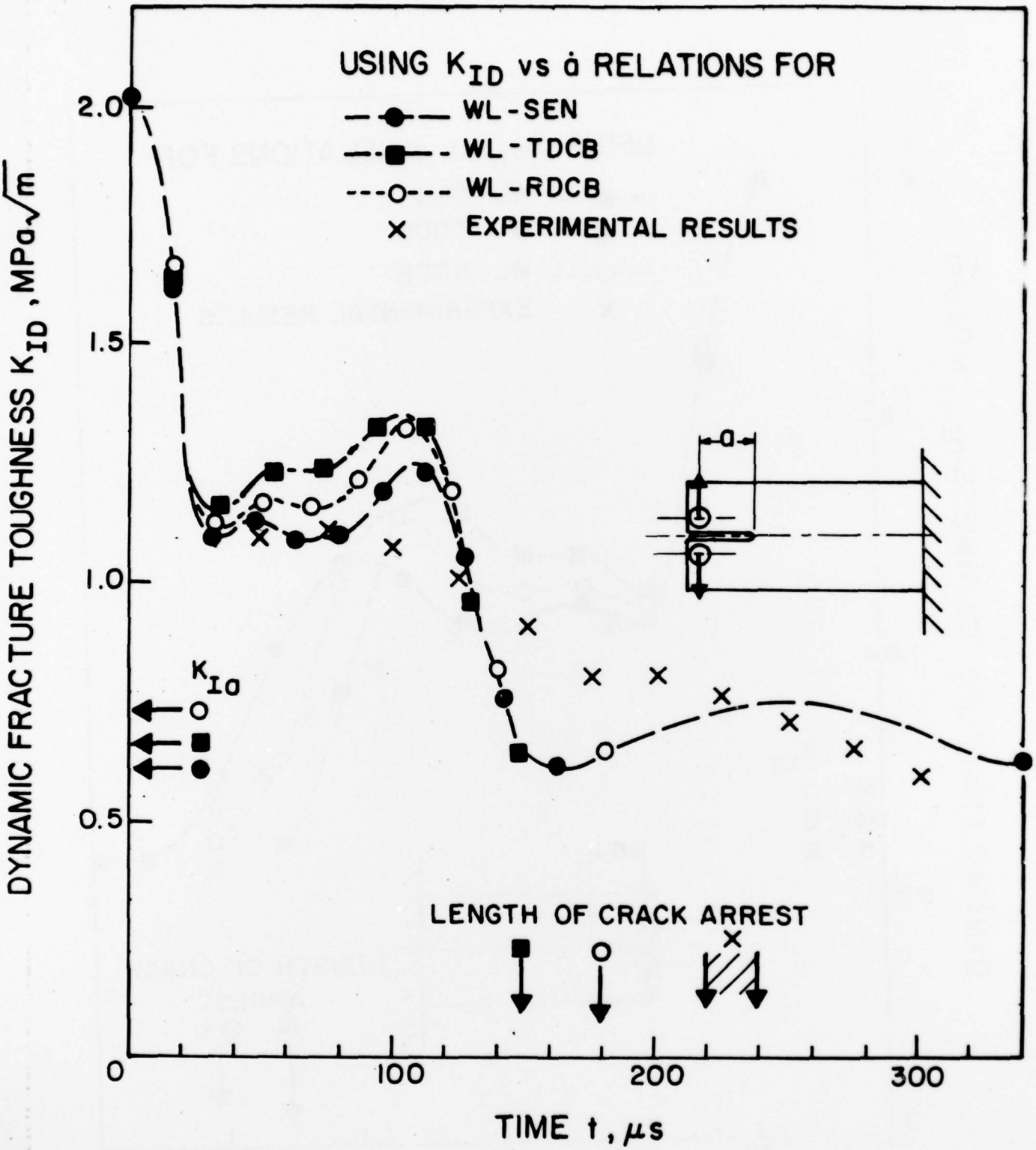

FIGURE 9. COMPUTED K_{ID} vs t OF WL- RDCB SPECIMEN.

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variations with crack propagations in the three specimens were compared with the corresponding experimental results. While the specific K_{ID} versus a relations established for each specimen obviously yielded calculated K_{ID} which were in best agreement with the experimental K_{ID} for the respective specimen, the K_{ID} versus a relations for the large WL-SEN specimen provided the best overall fit between the calculated and measured K_{ID} variations with crack propagation in all three specimens.